



Energy Harvesting and Health Monitoring Device

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Abstract: Continuous monitoring of vital health parameters is essential for the early detection of medical emergencies and effective patient care, particularly in remote and rural regions where healthcare facilities and communication infrastructure are limited[1]. Conventional health monitoring systems primarily rely on Wi-Fi, GSM, or internet connectivity[2],[3], which often suffer from restricted coverage, high power consumption, and frequent battery charging requirements[4]. This paper presents an Energy Harvesting Based Smart Health Monitoring Device Using LoRa Communication for Remote Healthcare Applications that enables reliable, low-power, and long-range health monitoring[5]. The proposed system integrates a MAX30102 sensor for heart rate and blood oxygen saturation (SpO₂) measurement, and an 16*2 LCD display for real-time visualization of health parameters. An Arduino nano microcontroller performs data acquisition, processing, and communication management, while a solar energy harvesting unit with rechargeable energy storage ensures self-sustained operation and minimizes dependence on external charging sources[7]. Health data are transmitted through LoRa technology, enabling communication over several kilometers without requiring cellular or internet networks[8]. In emergency situations, the system automatically[9]. The proposed solution offers enhanced energy efficiency, reliability, and cost-effectiveness, making it highly suitable for remote patient monitoring, elderly care, industrial worker safety, and disaster-response healthcare applications[10].

Keywords: Energy Harvesting, LoRa Communication, Health Monitoring System, Healthcare Device, Remote Patient Monitoring, MAX30102 Sensor, Arduino nano microcontroller, Solar-Powered device, Emergency Alert System.

I. INTRODUCTION

Healthcare monitoring has become a fundamental requirement in modern society due to the increasing prevalence of chronic diseases, aging populations, occupational health risks, and the growing need for continuous patient observation. Traditional healthcare systems primarily depend on periodic clinical visits and manual health assessments, which may not provide timely information about a patient's physiological condition during emergencies. Wireless sensor networks, and biomedical sensors have enabled the development of smart healthcare systems capable of continuously monitoring vital parameters such as heart rate, blood oxygen saturation (SpO₂), body temperature, and humidity. These technologies facilitate remote patient monitoring and improve healthcare accessibility, especially for elderly individuals, patients with chronic illnesses, and people residing in geographically isolated regions.

Although numerous healthcare monitoring solutions have been proposed, many existing systems rely heavily on Wi-Fi, Bluetooth, or GSM communication technologies for data transmission. These communication methods often suffer from limited coverage, high power consumption, network dependency, and reduced reliability in rural and remote environments where internet connectivity is unavailable or unstable. Furthermore, health monitoring devices generally require frequent battery charging, which limits their practicality for long-term deployment and continuous operation. In healthcare applications where uninterrupted monitoring is critical, battery depletion may result in delayed emergency response and loss of vital health information.

To overcome these limitations, Low-Power Wide-Area Network (LPWAN) technologies have emerged as promising alternatives for healthcare communication systems. Among these technologies, LoRa (Long Range) communication has gained significant attention due to its ability to provide long-range wireless communication while maintaining extremely low power consumption. LoRa technology enables reliable data transmission over several kilometers without requiring cellular infrastructure or continuous internet connectivity, making it particularly suitable for remote healthcare monitoring applications. Its low-power characteristics also contribute to prolonged device lifetime and reduced maintenance requirements compared to conventional wireless communication systems.



In parallel with advancements in communication technologies, energy harvesting techniques have become increasingly important for achieving self-sustaining healthcare devices. Solar energy harvesting offers an environmentally friendly and renewable power source capable of extending operational lifetime. By integrating energy harvesting mechanisms with low-power electronic components and efficient communication protocols, healthcare monitoring systems can operate autonomously for extended periods while maintaining reliable performance. Such self-powered systems significantly enhance portability, sustainability, and usability in field conditions and emergency healthcare scenarios.

This paper presents an Energy Harvesting Based Smart Health Monitoring Device Using LoRa Communication for Remote Healthcare Applications. The proposed device integrates a MAX30102 sensor for heart rate and blood oxygen saturation measurement, and an 16*2 LCD display for real-time health information visualization. An Arduino nano microcontroller serves as the central processing unit responsible for sensor data acquisition, processing, threshold analysis, and communication management. The system utilizes LoRa technology for long-range wireless transmission of health data and emergency notifications, while a solar energy harvesting unit with rechargeable energy storage provides sustainable power for continuous operation. In emergency situations, enabling rapid medical intervention. The proposed system aims to provide a reliable, low-cost, energy-efficient, and scalable healthcare solution for remote patient monitoring, elderly care, occupational safety, and disaster-response healthcare services.

The remainder of this paper is organized as follows: Section II presents the literature survey and related work, Section III discusses the research gap and proposed system, Section IV describes the methodology and system architecture, Section V explains the hardware and communication modules, Section VI presents the results and performance analysis, Section VII discusses applications and future enhancements, and Section VIII concludes the paper.

II. LITERATURE REVIEW

Healthcare monitoring systems have gained significant attention due to the increasing demand for continuous patient observation and early detection of medical emergencies. Researchers have developed various health monitoring devices capable of measuring physiological parameters such as heart rate, blood oxygen saturation (SpO₂), body temperature, and environmental conditions. These systems assist healthcare providers in monitoring patient health status and reducing the need for frequent clinical visits. However, communication range, power consumption, and energy sustainability remain major challenges in the practical deployment of remote healthcare systems.

Several researchers have utilized the MAX30102 sensor for monitoring heart rate and blood oxygen saturation. M. A. Hanson, H. C. Powell Jr., A. T. Barth developed a patient monitoring system using the MAX30102 sensor and an Arduino-based controller. Their system successfully measured physiological parameters and displayed the results locally. Although the sensing accuracy was satisfactory, the communication capability was limited and unsuitable for long-distance monitoring applications.

Proposed a health monitoring platform integrating pulse oximetry and heart-rate sensing technologies. The system provided continuous monitoring of patient vital signs and demonstrated reliable performance under normal operating conditions. However, the system monitored only a limited number of health parameters and lacked an efficient long-range communication mechanism.

Temperature monitoring is another important aspect of healthcare systems. Researchers have widely employed temperature and humidity sensors such as DHT11 due to their low cost and ease of interfacing with microcontrollers. Aosong Electronics Co., Ltd. implemented a health monitoring system incorporating DHT11 for environmental condition measurement. Their study showed that environmental parameters can influence patient comfort and health status. However, the communication range and power management aspects were not adequately addressed.

Wireless communication technologies play a critical role in remote monitoring systems. Traditional communication methods such as Bluetooth, ZigBee, and Wi-Fi have been extensively investigated for healthcare applications. Designed a wireless monitoring system using Bluetooth communication and demonstrated low-power operation. However, the communication range was limited to a few meters, making the system unsuitable for remote healthcare monitoring. Similarly, Wi-Fi-based solutions provide higher data rates but require network infrastructure and consume considerable power.

To overcome these limitations, researchers have explored Low-Power Wide-Area Network (LPWAN) technologies such as LoRa. Adelantado et al. analyzed the performance of LoRa communication and demonstrated its ability to support



long-range data transmission while maintaining low energy consumption. Their results indicated that LoRa is well suited for applications requiring reliable communication over several kilometers.

Jain and Sharma investigated the application of LoRa technology in remote monitoring systems and reported improved communication coverage compared to conventional wireless technologies. Their work highlighted the advantages of LoRa in terms of energy efficiency and communication reliability. However, the study focused primarily on communication performance and did not integrate comprehensive health-monitoring capabilities.

Rahman et al. developed a LoRa-based remote monitoring platform capable of transmitting sensor data over long distances. Experimental results showed stable communication performance and reduced packet loss under outdoor conditions. The study confirmed the suitability of LoRa communication for healthcare applications in rural and geographically isolated regions.

Emergency alert mechanisms have also been incorporated into healthcare systems to improve patient safety. Various researchers have proposed alarm-based monitoring systems that activate warning indicators when measured parameters exceed predefined threshold values. Such systems enable rapid response to abnormal health conditions and reduce the risk of delayed medical intervention. However, many existing solutions depend on external communication networks or cloud services for alert generation.

Energy consumption remains a significant challenge in healthcare monitoring devices. Continuous sensing, data processing, and wireless communication require a reliable energy source. To address this issue, researchers have investigated renewable energy harvesting techniques including solar energy harvesting. Solar-powered systems utilize photovoltaic panels to recharge rechargeable batteries and extend operational lifetime. Several studies have demonstrated that integrating solar panels with low-power microcontrollers and wireless communication modules can significantly improve energy sustainability and reduce maintenance requirements.

Arduino-based monitoring systems have become popular due to their low cost, simplicity, and compatibility with various sensors and communication modules. The Arduino Nano microcontroller offers sufficient processing capability for data acquisition, threshold analysis, display control, and wireless communication while maintaining low power consumption. Consequently, it has been widely adopted in health monitoring and remote sensing applications.

From the reviewed literature, it is evident that significant progress has been achieved in physiological sensing, LoRa communication, emergency alert systems, and renewable energy harvesting technologies. However, many existing systems suffer from limitations such as restricted communication range, dependence on external networks, limited health parameter monitoring, absence of integrated alert mechanisms, and insufficient energy autonomy. Therefore, there remains a need for a self-powered health monitoring system capable of continuously monitoring multiple physiological parameters while providing reliable long-range communication and emergency alerts.

The proposed Energy Harvesting Based Smart Health Monitoring Device addresses these limitations by integrating MAX30102 SpO₂ sensing, HW-827 pulse monitoring, DHT11 temperature and humidity sensing, Arduino Nano-based processing, solar-powered energy management, LoRa SX1278 long-range communication, LCD-based local monitoring, and buzzer-based emergency alerts into a unified and cost-effective healthcare monitoring platform.

III. SYSTEM ARCHITECTURE

The proposed Energy Harvesting Based Smart Health Monitoring Device consists of a solar-powered energy management unit, health sensing module, processing unit, wireless communication module, and remote monitoring station. A 12V solar panel charges two 18650 Lithium-Ion batteries through a power management/charge controller module, ensuring a stable power supply for continuous operation. The health sensing module includes the MAX30102 sensor for measuring blood oxygen saturation (SpO₂), the HW-827 pulse sensor for monitoring heart rate, and the DHT11 sensor for measuring temperature and humidity. An Arduino Nano acts as the transmitter-side controller, collecting and processing sensor data before sending it through the LoRa SX1278 transmitter module. The sensed data is wirelessly transmitted using LoRa communication to the receiver unit, where another LoRa SX1278 module and Arduino Nano receive and process the information. The received health parameters, including SpO₂ (%), Heart Rate (BPM), Temperature (°C), Humidity (%), Solar Panel Voltage (V), and Current (A), are displayed on a 16×2 LCD display with an I2C interface.

The receiver continuously performs abnormal condition analysis. If any health parameter exceeds predefined threshold values, an alarm buzzer is activated to alert caregivers or healthcare personnel. Under normal conditions, the buzzer remains off. This architecture provides continuous health monitoring, long-range wireless communication, low power



consumption, solar-powered operation, and reliable remote patient monitoring, making it suitable for healthcare applications in remote and resource-limited areas.

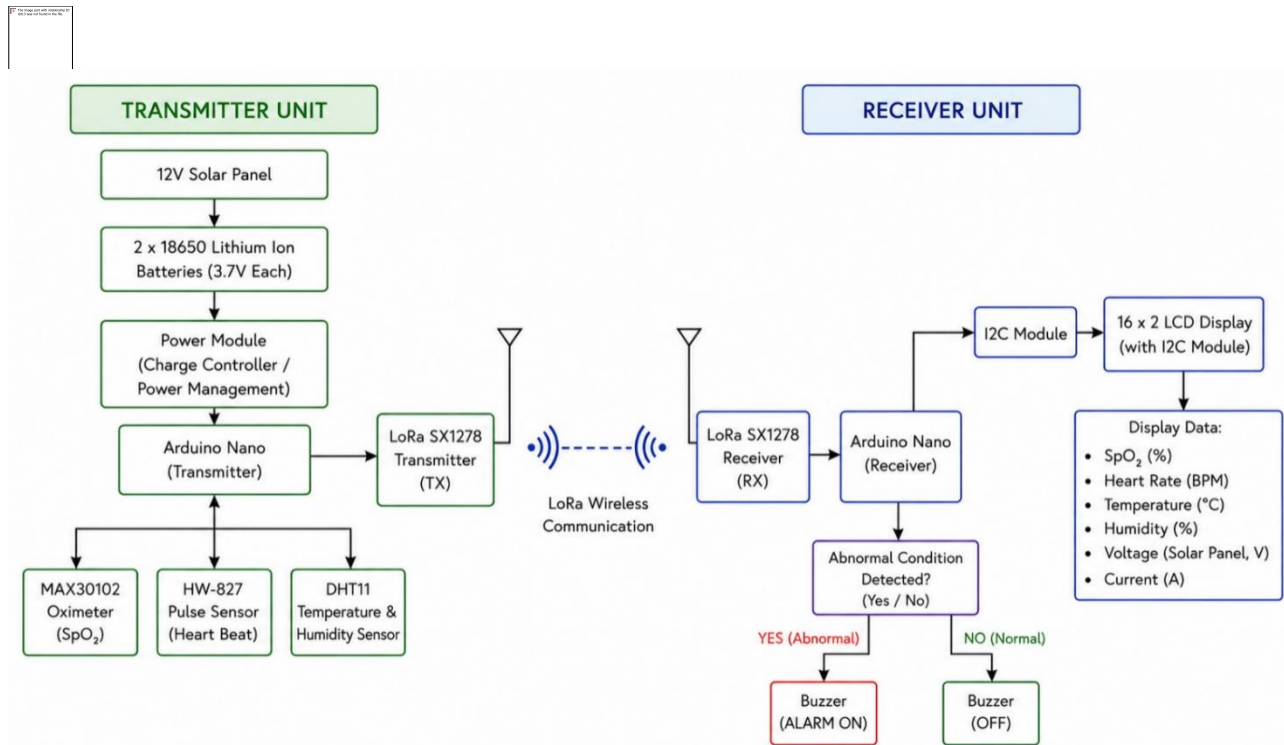


Fig. 1. System Architecture Diagram

The proposed Energy Harvesting Based Smart Health Monitoring Device is designed to continuously monitor a user's health parameters and transmit the collected information over long distances using LoRa communication technology. The system is divided into five major units: Power Management Unit, Sensor Unit, Processing Unit, Communication Unit, and Monitoring Station.

1. Power Management Unit

The power management unit supplies electrical energy to the entire system. A solar panel captures sunlight and converts it into electrical energy. This energy is managed through a power management module and stored in rechargeable 18650 Lithium-Ion batteries. The regulated power is supplied to the Arduino Nano, sensors, LoRa modules, LCD display, and buzzer. The solar energy harvesting mechanism reduces dependence on external power sources and enables continuous operation of the health monitoring system.

2. Sensor Unit

The sensor unit continuously monitors the patient's physiological and environmental parameters. The MAX30102 sensor measures blood oxygen saturation (SpO₂), while the HW-827 pulse sensor measures heart rate in beats per minute (BPM). The DHT11 sensor measures ambient temperature and humidity. These sensors acquire real-time data and transmit it to the Arduino Nano microcontroller for processing and analysis.

3. Processing Unit (Arduino Nano)

The Arduino Nano serves as the central processing unit of the transmitter section. It collects data from the MAX30102, HW-827 pulse sensor, and DHT11 sensor. The acquired sensor readings are processed and compared with predefined threshold values to identify abnormal health conditions. The Arduino Nano controls data acquisition, sensor interfacing, and communication operations. After processing, the sensor data is transmitted to the LoRa communication module for long-range wireless transmission.

4. Communication and Display Unit

The communication unit utilizes LoRa SX1278 transmitter and receiver modules to provide long-range wireless communication. The transmitter-side LoRa module sends the processed health data to the remote receiver station. At the



receiver side, another Arduino Nano receives and processes the incoming data. The received information, including SpO₂ level, heart rate, temperature, humidity, solar panel voltage, and current, is displayed on a 16×2 LCD display using the I2C interface. LoRa communication enables reliable data transmission over long distances while maintaining low power consumption.

5.Alert and Monitoring Unit

The alert and monitoring unit continuously checks the received health parameters for abnormal conditions. If any parameter exceeds its predefined threshold value, the Arduino Nano activates a buzzer to generate an immediate warning alert. Under normal operating conditions, the buzzer remains inactive. The LCD display provides real-time monitoring of all measured parameters, allowing healthcare personnel or caregivers to observe the patient's condition remotely. This alert mechanism ensures timely identification of potential health emergencies and improves patient safety.

IV. METHODOLOGY

The proposed Energy Harvesting Based Smart Health Monitoring Device continuously monitors vital health parameters and transmits the collected information to a remote monitoring station using LoRa communication technology. The system integrates physiological sensors, Arduino Nano microcontrollers, solar energy harvesting, long-range wireless communication, and an alert mechanism to provide a reliable healthcare monitoring solution for remote environments.

A. System Initialization

When the device is powered on, the power management unit supplies regulated power to all hardware components. The solar panel harvests solar energy and charges the rechargeable 18650 Lithium-Ion batteries through a power management module. The regulated voltage is supplied to the Arduino Nano microcontroller, sensors, LoRa modules, LCD display, and buzzer. After initialization, the Arduino Nano configures the sensor interfaces and establishes communication with the LoRa transmitter module for data transmission.

B. Health Data Acquisition

The sensing unit continuously acquires physiological and environmental data. The MAX30102 sensor measures blood oxygen saturation (SpO₂), while the HW-827 pulse sensor measures heart rate in beats per minute (BPM). The DHT11 sensor measures ambient temperature and humidity. Sensor readings are periodically collected by the Arduino Nano and prepared for further processing and transmission.

C. Data Processing and Analysis

The Arduino Nano processes the acquired sensor data and validates the measured values. The physiological parameters are compared with predefined threshold values to identify abnormal health conditions. The controller continuously analyzes SpO₂ level, heart rate, temperature, and humidity readings. If all parameters remain within normal limits, the system continues normal monitoring operation. Any abnormal reading is immediately detected and marked for alert generation.

D. LoRa-Based Wireless Communication

After processing, the transmitter-side Arduino Nano packages the sensor data and sends it to the LoRa SX1278 transmitter module. The LoRa module wirelessly transmits the information to the remote receiver station using long-range, low-power communication. LoRa technology enables reliable communication over several kilometers while consuming very little power. The receiver-side LoRa SX1278 module receives the transmitted data and forwards it to another Arduino Nano for display and monitoring.

E. Real-Time Display and Remote Monitoring

At the receiver station, the Arduino Nano processes the received sensor information and displays it on a 16×2 LCD display using the I2C interface. The LCD continuously shows important parameters such as blood oxygen saturation (SpO₂), heart rate (BPM), temperature, humidity, solar panel voltage, and current. This enables healthcare personnel or caregivers to monitor the patient's condition remotely without requiring internet connectivity.

F. Emergency Detection and Alert Generation

The system continuously checks all received health parameters against predefined safety limits. If abnormal conditions such as low SpO₂, irregular heart rate, or abnormal temperature are detected, the receiver-side Arduino Nano activates a buzzer to generate an immediate warning alert. The alert mechanism helps caregivers quickly identify potential medical emergencies and take necessary action. During normal operating conditions, the buzzer remains inactive.



G. Energy Harvesting and Power Management

To ensure continuous operation, the system utilizes solar energy harvesting. The solar panel converts sunlight into electrical energy, which is stored in rechargeable 18650 Lithium-Ion batteries. The power management circuit regulates battery charging and distributes stable power to all system components. This renewable energy approach reduces dependence on external charging sources, increases operational lifetime, and improves the sustainability of the health monitoring system.

H. Continuous Monitoring Operation

The entire process of sensing, processing, transmission, display, and alert generation operates continuously in a cyclic manner. The health parameters are monitored in real time, transmitted through LoRa communication, displayed at the receiver station, and analyzed for abnormalities. This ensures reliable remote health monitoring with low power consumption and long-range communication capability.

V. RESULT

The proposed Energy Harvesting Based Smart Health Monitoring Device was successfully developed and tested to evaluate its sensing performance, communication reliability, and energy efficiency. The MAX30102 sensor accurately measured blood oxygen saturation (SpO₂), while the HW-827 pulse sensor provided reliable heart-rate measurements in beats per minute (BPM). The DHT11 sensor successfully monitored ambient temperature and humidity conditions. Experimental observations demonstrated that the system could continuously acquire and process health-related data in real time..

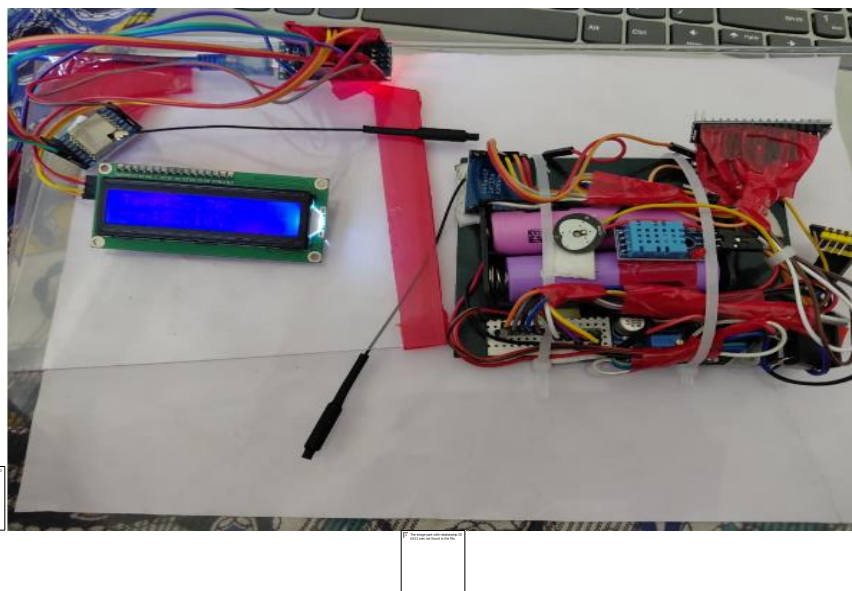


Fig. Prototype of Energy Harvesting Based Smart Health Monitoring Device

Fig. shows the developed prototype of the Energy Harvesting Based Smart Health Monitoring Device. The transmitter unit consists of the Arduino Nano, MAX30102 sensor, HW-827 pulse sensor, DHT11 sensor, LoRa transmitter module, solar power supply, and battery management system. The receiver unit consists of the LoRa receiver module, Arduino Nano, LCD display, and buzzer alert system.

The receiver unit successfully received the transmitted data and displayed the measured parameters on the 16×2 LCD display in real time. The displayed information enabled continuous monitoring of patient health conditions without requiring internet connectivity. The system maintained stable communication between the transmitter and receiver nodes throughout the testing period.

Performance evaluation demonstrated that the LoRa communication module provided reliable long-range wireless communication with low power consumption. The communication system effectively transmitted sensor data between the monitoring units, making it suitable for healthcare applications in rural and remote locations where conventional network infrastructure may not be available.



The solar energy harvesting unit effectively supported battery charging and continuous system operation. The solar panel generated electrical energy, which was stored in rechargeable 18650 Lithium-Ion batteries through the power management circuit. This arrangement reduced dependence on external power sources and improved the operational lifetime of the system. The emergency alert mechanism was also evaluated under abnormal operating conditions. Whenever the measured parameters exceeded predefined threshold values, the buzzer was successfully activated, providing an immediate warning indication. This feature enhances patient safety by enabling caregivers and healthcare personnel to quickly identify abnormal health conditions.

VI. CONCLUSION

The proposed Energy Harvesting Based Smart Health Monitoring Device was successfully developed and tested for continuous monitoring of SpO₂, heart rate, temperature, and humidity. The system effectively utilized Arduino Nano, LoRa SX1278 communication, and solar energy harvesting to achieve reliable health monitoring with low power consumption. Real-time data display and buzzer-based alert generation enhanced patient safety and monitoring efficiency. The results demonstrate that the proposed system is a cost-effective, energy-efficient, and reliable solution for remote healthcare monitoring applications.

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